Recommendations of a national working group on prevention and control of rabies in the United States

Article III: Rabies in wildlife

Cathleen A. Hanlon, VMD, PhD; James E. Childs, ScD; Victor F. Nettles, DVM; ¨ the National Working Group on Rabies Prevention and Control*

From the Centers for Disease Control and Prevention, 1600 Clifton Rd NE, Atlanta, GA 30333 (Hanlon, Childs), and the Southeastern Cooperative Wildlife Disease Study, College of Veterinary Medicine, University of Georgia, Athens, GA 30602-7393 (Nettles).

*Other members of the Working Group are listed at the end of the article.

The complexity of controlling rabies has increased dramatically in the United States since wildlife began to replace domestic dogs as the principal disease vector > 40 years ago.[1] Extensive use of veterinary clinics for parenteral vaccination of domestic dogs, observation of the suspect biting animal, and public education campaigns (together with the application of **postexposure prophylaxis [PEP]** following a dog bite) during the 1950s and 1960s were effective, simple strategies for the management of rabies in dogs. However, these strategies were not directly applicable to the management of rabies in wildlife.

Management of rabies in wildlife is complicated by the ecologic and biologic factors associated with wildlife reservoirs, the multiagency approach needed to manage an important public health problem originating in wildlife, the limitations of available control methods, and the broad range of public attitudes toward wildlife. In addition, there are several variants of the rabies virus in the United States.[2,3] These are associated with terrestrial carnivores, including raccoons, skunks, and arctic, red, and gray foxes; a number of variants are also found in a variety of species of bats. Recently, an apparent viral shift or adaptation developed with a variant of the virus in canids at the United States-Mexico border area, resulting in local transmission among coyotes and dogs in south Texas.[4] Compounding the problem, animals infected with this variant were translocated to other states.[5] There are equally important biologic, behavioral, and ecologic differences among carnivores that imply inherent differences in disease control approaches to each major reservoir.

It is often difficult to examine the precise epizootic characteristics of rabies as it spreads among animals of a given population. Also, the role of reservoir host abundance and demography is poorly understood. However, it is possible to make several generalizations from passive surveillance data and trends in the reporting of cases of rabies in animals, especially from detailed studies of red fox populations in Europe. Where measures of carnivore abundance exist, the incidence of rabies in animals (presumably all species) is often positively associated with the increasing density of a dominant reservoir species.[6] In general, rabies epizootics affecting carnivores spread in wavelike fashion; the area experiencing the current epizootic is the crest, and the locale with low reservoir-host populations is the trough.[7] Rabies is viewed as a density-dependent disease, and population dynamics of reservoir hosts are regarded as critical to understanding and modeling the temporal and spatial patterns of rabies in wildlife.[8,9] In part, the rate of spread of rabies in populations of a particular species can be related to, or modeled by, its social structure, dispersal patterns, and contact rates.[8,10,11] Habitat features, such as continuity and patch size, may play a role in the rate of spread and persistence of the disease.[12,13] Furthermore, interactions among species complicates the understanding of the ecologic and epidemiologic factors associated with rabies.[14] Spillover of infection from the dominant reservoir of a region to other species has been documented,[2] but the processes by which new variants and epizootics of rabies virus emerge in different reservoir species are unknown. After an epizootic has abated, terrestrial reservoir populations decrease, and reports of rabies in animals in a given locale can decline precipitously. An apparent host threshold density has been suggested as necessary for rabies to perpetuate in red fox populations.[15] Below this threshold, contacts appear too few to continue transmission. The threshold phenomenon has not been well studied in other species, although it is presumed to exist. In addition, immunity in surviving members of the reservoir population has been suggested for several species following an epizootic of rabies.[14] The influence of herd immunity and population recovery time in the recrudescence of rabies in enzootic areas are largely unstudied for the terrestrial rabies reservoirs; the situation is similar for the various species of bats and diverse rabies virus variants of bats.

There are a number of approaches for management of rabies in wildlife, such as reduction of vector populations, modification of habitats, parenteral vaccination through **trap-vaccinate-release (TVR)** programs, oral vaccination, and passive disease surveillance. In addition, immunocontraception for limiting wildlife populations and modulating density-related disease is an intriguing and rapidly progressing area of research, although it is still considered highly experimental.[16] These various methods could be used alone or in combination. The utility of wildlife control methods, either independently or in an integrated control program, will depend in large part on the overall objectives. Objectives for the control of rabies may vary regionally, from state to state, and within a state. State wildlife agencies with the statutory authority to manage wild animals may not universally endorse the same management strategy as their respective state public health agencies. Moreover, the existence of rabies reservoirs in multiple states (with the exception of mongooses and their unique rabies virus variant in Puerto Rico) makes strategic control of rabies a national issue. Oral vaccination programs for carnivores are in developmental or early operational stages, and their field efficacy, costs, and benefits remain uncertain. Conventional management approaches, such as long-term, federally supported population reduction on a broad scale, no longer appear justified relative to social acceptability, cost, and efficacy. Lastly, wildlife reservoir species, unlike domestic animals, are natural resources; therefore, public input is essential in helping to determine the methods used to manage rabies among these animals.[17]

Rabies Vector Population Reduction

Historically, population reduction has been used to control rabies on the premise that densities of susceptible animals can be reduced below a threshold necessary for rabies to spread through populations.[18] The efforts to control rabies in skunks in Alberta, Canada represents one of the only recent, documented, and broader-scale uses of population reduction in North America conducted explicitly to control rabies. Success of the control program in Alberta was attributed to a high level of effort during several years, the well-defined behavior of skunks in prairie habitats, and access to an effective method.[19] Compensatory changes in carnivore reproduction and dispersal can limit the effectiveness of controlling population numbers of other species in different conditions.[9,20]

Population reduction with toxicants is impractical as a broadscale control alternative for rabies in the United States. Presidential Executive Order 11643, issued in 1972, banned the use of toxicants (compound 1080, strychnine, sodium cyanide, and thallium sulfate) for control of predators.[21] The M-44 cyanide capsule has been reregistered with some applicability for controlling rabies vectors (coyotes and red and gray foxes).[22] In addition, research conducted by USDA Animal Damage Control (recently renamed Wildlife Services) has led to the development of a large gas cartridge that may be used for lethal elimination in dens of skunks, coyotes, and red foxes. Similarly, there is a commercially produced gas cartridge for use on denning skunks (also with moles, woodchucks, or other rodents). Various types of traps and aerial and ground shooting could potentially be used with toxicants in an integrated population reduction strategy to control rabies in some species. However, trapping and shooting options for population reduction of wildlife species would require the opportunity for extensive review by and input from all potentially affected stakeholders.

The estimated costs of population reduction vary widely[18,23]; however, such efforts would most likely be cost prohibitive if programs relied on labor-intensive trapping and shooting.[18] Other issues, such as impacts to nontarget species[24] and limited public support for population reduction efforts, clearly restrict the feasibility of this approach as a single tactic for broad-scale control of rabies. Presently, population reduction is most likely to be publicly accepted and effective in localized or site-specific scenarios in the United States (eg, reducing the density of raccoon populations in parks where visitors may come in contact with potentially rabid animals). The use of intensive local population reduction as a contingency to address outbreak foci remains untested. Population reduction also may continue to merit consideration for species or situations in which all other methods are not practical.

Habitat Modification

Habitat modification is a useful site-specific management approach that can reduce the chance of interaction between human beings and potential vectors like skunks, raccoons, and bats. Managing refuse through routine garbage pickup, using animal-proof garbage receptacles, making pet food inaccessible to wild animals, capping chimneys, and screening louver vents are examples of habitat manipulation to minimize contact between wild animals, pets, and people. Techniques designed to prevent access of bats to human living quarters can minimize PEP considerations.

Trap-Vaccinate-Release Programs

A TVR program was implemented in Toronto in 1984[11] as an interim measure to control rabies in skunks until an **oral rabies vaccine (ORV)** could be developed. Inactivated rabies virus vaccine was injected IM into live-trapped skunks. Serum samples from recaptured animals indicated that a high level of population immunity was effective in reducing rabies in Toronto. Costs were relatively high ($450 to $1,150/sq km [US dollars]) for the TVR program in Toronto, but these costs may be offset partially by a reduction in the number of people receiving PEP.[25] Similarly, there have been TVR programs targeting raccoons on the Delmarva (Delaware, Virginia, and Maryland) peninsula,[a] in Philadelphia,[b] and in Ithaca, NY.[c] A TVR program is also being implemented along the Ontario boundary of the Niagara Frontier in an attempt to provide a barrier against the invasion of rabid raccoons.

Oral Rabies Vaccination

After the concept was conceived at the **Centers for Disease Control and Prevention (CDC)** during the 1960s, oral vaccination of red foxes with attenuated Evelyn-Rokitnicke-Abelseth vaccine was demonstrated in the early 1970s.[26] The intensity of rabies in foxes in Europe stimulated the further development of vaccines and delivery systems,[27] and these efforts were supported by the World Health Organization. Early control efforts included ground and aerial delivery of rabies vaccine in blister packs inserted in chicken head baits. Oral vaccination in Europe has since progressed to include the use of several efficacious vaccines, including attenuated and recombinant rabies vaccines, in a variety of commercial baits; these are distributed through a combination of ground and aerial bait distribution methods.[28] During 1999, Switzerland, which had a long enzootic for rabies in red foxes and was the first country to use ORV in wildlife in 1978, was declared free of rabies.

In 1989, a similar ORV program was implemented in southern Ontario. Efforts in Ontario throughout the past decade have been promising and have greatly advanced aerial bait delivery with fixed-wing aircraft over large, homogenous areas of land.[29] The ultimate objective of eliminating the arctic fox variant of the rabies virus, which is transmitted among red foxes in the region, may hinge in part on cooperation with neighboring northeastern states and provinces.

Although oral vaccination shows promise for control of rabies among some terrestrial vectors, many important questions regarding baits, optimal baiting strategies, and relevant techniques for control of rabies in bats remain unanswered.[1] Subsequent to placebo baiting studies to evaluate the feasibility of oral vaccination,[30-32] the potential benefits of oral vaccination have been questioned.[33] In contrast, the public is often supportive of novel control methods,[34] despite the infancy of oral vaccination for control of rabies among terrestrial vectors in the United States. To warrant consideration as a public health intervention, efficacy of oral vaccination must be proven, and desirable cost-benefit ratios or a willingness to pay among the general public or other stakeholders will be required.[35-36]

In the United States, international and multidisciplinary collaborative efforts led to the development of a **vaccinia-rabies glycoprotein (V-RG)** recombinant virus vaccine for use in raccoons.[37-42] In 1997, the results of safety and efficacy field trials led to full licensure of the V-RG vaccine for use in state or federally approved oral vaccination projects targeting raccoons.[43] To date, the V-RG vaccine has been used in > 10 completed or ongoing field projects for control of rabies in raccoons.[1,44] The potential effectiveness of oral vaccination at containing epizootic fronts was first described in New Jersey[45] at the Cape May peninsula and subsequently at the Cape Cod isthmus in Massachusetts.[46] The first suppression of rabies in an enzootic area was described in the Capital Region of New York.[1] Additional ongoing pilot studies have yet to generate substantial data on which to base operational plans for control of rabies through oral vaccination.[1] However, it is clear that federal involvement in strategic oral vaccination efforts involving multiple states will be essential if the ultimate goal is elimination of a particular terrestrial variant of rabies virus. In addition to pilot studies for control of rabies in raccoons, the V-RG vaccine is also being used in an effort to prevent the spread of rabies among gray foxes in west Texas and among coyotes in south Texas.[47]

Surveillance

Surveillance is integral to all efforts of rabies control. Surveillance should be pursued more aggressively and with an analytic design during control field trials to objectively evaluate effectiveness. National typing of rabies virus variants should be continued, because such efforts would lead to better understanding of the spatial and temporal distribution of different variants. Such information is essential in view of the differences in behavior and population dynamics and structure among the major wildlife vectors. If regional control efforts directed at specific variants of the virus are initiated, historic and current surveillance data on variants will be needed. Basic passive surveillance will be insufficient for monitoring the effect of oral vaccination on rabies in wildlife.

Contraception

Interest in oral contraception in wildlife began in the early 1960s as a means to control coyote populations causing livestock depredations in the west and red fox populations responsible for the spread of rabies in the eastern United States.[48] Research efforts with the reproductive inhibitor diethylstilbestrol had promise,[49] but these were abandoned because of the lack of safe, effective, long-lasting agents, and effective delivery systems. Recently, contraception has regained attention as a means of controlling wildlife populations.[16] Advances in genetic technology since the 1960s have led to the development of immunocontraceptives.[50-52] Nevertheless, field delivery of oral immunocontraceptives presents many of the same challenges that confronted researchers of oral rabies vaccination in the 1960s. Much work remains to develop safe and effective delivery systems.[48,50,53,54] In addition, many stakeholders will have a voice in defining the conditions under which immunocontraceptives could be acceptably applied.[55]

Recommendations—A better understanding of the complex interaction of host factors (eg, density dependent changes in reproduction, survival, and dispersal, and level of immunity in the surviving population) and viral characteristics involved in epizootic and enzootic transmission of rabies in wildlife populations is necessary. Surveillance systems that include detailed ecologic or epidemiologic data are needed. Explicit descriptions of the impact of rabies on the population dynamics of carnivores and the potential effect of interventions, such as oral vaccination, are fundamentally lacking and critically needed. Educational materials for the public on rabies in wildlife and potential control measures also are inadequate or lacking. Practical and effective vaccines that generate immunity to rabies or inhibit reproduction in specific species are needed. Basic dynamics, movement, and dispersal patterns of rabies vectors should be more fully investigated, particularly in relation to proposed disease control through oral vaccination or other techniques. Professional societies with diverse interests (ecology, mammalogy, wildlife biology, virology, and epidemiology) should collaborate and inform their members of activities in related fields through solicited papers and symposia. More complete species identification on animals, such as bats, submitted for testing should be completed by trained diagnostic laboratory personnel or through collaboration with mammalogists to correct potential laboratory personnel limitations with regard to taxonomic classification of animals submitted for diagnosis of rabies.

In addition to rabies surveillance of wildlife through conventional passive public health submissions, strategic application of active surveillance, such as at epizootic fronts and in areas implementing oral vaccination, will be critical. More effective use of available sources of data should be considered, including augmenting surveillance data collection at the state level. Information on specific geographic location and disease status of all animals submitted for testing should be reported and retained. Existing surveillance systems should be integrated within geographic information system databases, especially databases that would enable classification of habitat features. This would facilitate the understanding of the population dynamics and habitat relationships of reservoir species and potential spread of disease. Educational materials on rabies in wildlife and potential control measures need to be compiled and made available for widespread public distribution as requested by the public. The potential benefits of oral vaccination and other integrated control strategies should be thoroughly described for various major application strategies, such as suppression of local intensity of rabies, containment of an epizootic front, and proposed elimination of a terrestrial rabies variant. Research leading toward the development of practical contraceptives or related technology for managing wildlife populations should be encouraged and supported. Symposia that bring veterinarians, wildlife managers, and other stakeholders together for collaboration on management strategies should be conducted.

Authority for Management of Rabies in Wildlife

Timely and appropriate response concerning human or domestic animal exposure to rabies should be a local action. However, it is important for responses to be standardized and based on sound public health policy that requires protocols be developed at the state level, using national guidelines.[56] At the local level, a variety of agencies and individuals may be involved in managing exposure to rabies (eg, animal control officers, health department personnel, emergency room staff, and veterinarians). This multiagency involvement can be confusing for many citizens who may not know the responsible party to call in the event of an exposure. Such confusion can also lead to lack of coverage when clear lines of responsibility are not stated. Recommendations have been prepared by the National Association of State Public Health Veterinarians and the Advisory Committee on Immunization Practices, but these guidelines do not address specific logistic issues at the local level.

Recommendations—State and local task forces consisting of representatives of all involved agencies should be formed to make recommendations for improving communication and coordination at both levels. The health department should be the single authority at the local (city, county, or town) and state levels designated to establish protocols for the management of human exposure to wildlife and to ensure that protocols are followed. State health departments, cooperating with other state agencies (eg, agriculture, wildlife) and using information from recognized national authorities, should provide localities with guidelines and protocols, including those for the scientific rationale for managing wild and domestic animals that potentially expose humans or domestic animals. The public should be notified by various means as to appropriate contacts in the event of an exposure. The system of reporting exposures should be simple and should include 24-hour coverage for nights, weekends, and holidays. If local police or animal control dispatchers receive the information, it should be transmitted to the appropriate individual or agency (eg, health department, animal control, game warden) for response. In all instances, procedures should ensure that the health department is notified of any suspected exposure to rabies. Records should be kept of all potential exposures and eventual outcomes.

Management of Wildlife to Minimize Transfer of Disease

Throughout history, wild animals have been captured, moved, and released by human beings. In a report by Nielsen,[57] conservation, ecology, commerce, recreation, and humanitarian concerns were cited as the primary reasons for translocation of wildlife. Many benefits may be derived through translocation of wild animals, such as restoration of rare or endangered species and expansion of genetic variability of specific isolated populations. However, translocation of animals also has the potential for significant negative impact, particularly with regard to inadvertent transfer of pathogens. For example, there is evidence that the 1977 mid-Atlantic focus of the rabies epizootic in raccoons was the result of long-distance translocation of infected raccoons from the southeastern United States.[58-60] More recently, the coyote-dog variant of the rabies virus, previously known only from the United States-Mexico border,[4] was diagnosed in American Foxhounds in Alabama and Florida.[5] The cases were linked to commercial fox-chasing pens[61] that had stocked coyotes[5] and were contained. Intensive use of commercial enclosures created a need to restock animals and led to interstate commercial traffic in wild-caught foxes and coyotes.[61,62] In response, state regulations regarding fox-chasing enclosures and sale of live foxes and coyotes are rapidly evolving,[63] but compliance remains a problem.[62] In another recent incident, rabies was diagnosed in gray foxes transported from Texas to Montana. Genetic analysis revealed that the isolate was a gray fox variant found in west Texas.[3] Similar episodes have involved the translocation of bats from the United States to Europe.

Short-distance relocation of nuisance wildlife may also affect the local incidence of rabies. The most important reservoirs, such as raccoons, skunks, foxes, and various species of bats, are capable of living in close association with people, particularly where "suburbanization" results in adequate shelter and food. Nuisance wildlife are killed or captured and removed by property owners, private pest control operators, licensed commercial trappers, and municipal, state, or federal animal control or wildlife management personnel. Often, landowners express a strong desire that the animals be removed unharmed and transported elsewhere for release. Although relocation is often local, this transportation of animals may provide a mechanism for rabies to spread more rapidly into contiguous, susceptible populations or to surmount geographic or artificial immunologic barriers, such as those caused by oral vaccination of rabies in wildlife.

Recommendations—Stronger and more uniform federal and state wildlife regulations are necessary to prevent indiscriminate international, interstate, and intrastate movement and release of wild carnivores by private citizens. Effective enforcement of state wildlife regulations is necessary to deal with intrastate relocation of wild carnivores. Guidelines are critically needed for determining when nuisance wildlife should be euthanatized instead of being released. Regulations pertaining to the live release of nuisance animals that are vectors for rabies need to be more restrictive. Under the jurisdiction of the state's wildlife, agriculture, or public health agency, each state should have or develop regulations regarding the rehabilitation, capture, holding, sale, and release of wildlife, particularly the importation of wild-caught carnivores.

States with endemic rabies in a given species should develop regulations prohibiting—except under special permit—the assembly of live, wild animals of that species for any purpose including intra- or interstate sales. Violations of state regulations on import of wild animals should be prosecuted through a joint effort between the state and the US Fish and Wildlife Service, thereby activating the penalties associated with violations of the Lacey Act.[64]

Public education programs should be developed to explain public health risks and the need for regulations on relocation of wildlife. Information should address the zoonotic disease risks issues associated with translocation of wildlife. Stronger federal regulation of international animal importation, including the prohibition, quarantine, or restricted movement of exotic species capable of introducing or perpetuating nonindigenous Lyssaviruses, is required.

Implementation of Vaccination Programs for Wildlife

Use of ORV in the United States is restricted by the USDA to state or federally approved control programs targeting raccoons, with additional applications underway in Texas targeting coyotes and gray foxes. Parenteral vaccines have not been licensed for use in wildlife. Use of ORV should be reserved for large-scale attempts to eliminate or reduce the impact of an outbreak of rabies in wildlife or to limit entry of rabies from wildlife into an area; ORV should not be used for the vaccination of individual animals. Currently, there is no officially delegated lead agency to monitor or evaluate the use of ORV once they are fully licensed.

Recommendations—A national strategy should be formulated for the use of ORV in wildlife, and a federal agency should be designated to lead wildlife vaccination efforts. A single agency within each state should be designated to coordinate rabies vaccination programs in consultation with the other involved agencies. Oral vaccination programs should be optimized through investigations of various bait densities and distribution methods. The CDC should provide technical laboratory and logistic assistance in the conduct, coordination, and surveillance evaluation of state programs, including communication and coordination with other participating state and federal agencies. The USDA should assist in implementation of control programs. Universities and other groups could play various roles, including research, evaluation, and technical support; however, these roles should be secondary to the activities of state and federal agencies. State authorities from public health agencies and either the designated public health veterinarian or the state veterinarian from agriculture departments should have ultimate responsibility for the conduct, supervision, coordination, and termination of wildlife vaccination programs in their respective states. These activities should be coordinated between state departments of agriculture and wildlife. This effort can be expedited by the formation of an interdepartmental task force or committee representing at least those 3 agencies responsible for public health, agriculture, and wildlife. Other potential members for such a task force include private and academic veterinary and human medical practitioners and biomedical researchers.

Since the meeting of the 1995 working group, measurable, but somewhat limited, progress has been made toward control of rabies in wildlife. More areas are using ORV since the vaccine has become licensed. Further westward advancement of rabies in raccoons appears to have been stalled by a considerable ORV effort in the first affected Ohio counties, adjacent to Pennsylvania. However, the recent advancement of rabies northward from New York to eastern Ontario, despite prevention measures in the area (ORV in New York and TVR in Ontario), exemplifies the weakness of current control methods and the lack of guidelines toward efficacious application. Application of ORV in Texas has restricted the progression of rabies in coyotes and gray foxes. Clearly, ORV and other management methods are currently novel tools in the prevention and control of rabies in the United States. For these control methods to become practical, numerous aspects of the various techniques will require additional development and evaluation. Economic analysis and field assessment is in progress.

Members of the National Working Group on Rabies Prevention and Control:
George R. Anderson, DVM, MPH (retired), Michigan Department of Public Health, Lansing; Matthew Cartter, MD, MPH, Connecticut Department of Public Health, Hartford; James E. Childs, ScD, CDC, Atlanta, Ga; Cathy J. Clark, the Texas Animal Control Association, Lufkin; Keith A. Clark, DVM, PhD, DACVPM (retired), Texas Department of Health, Austin; William R. Clark, PhD, Iowa State University, Ames; Joseph Corn, Southeastern Cooperative Wildlife Disease Study, the University of Georgia, Athens; John G. Debbie, DVM (retired), New York State Department of Health, Albany; Millicent Eidson, MA, DVM, DACVPM, New York State Department of Health, Albany; Makonnen Fekadu, DVM, PhD, CDC, Atlanta, Ga; Edward A. Fitzgerald, PhD (retired), FDA, CBER/DPQC, Rockville, Md; Cathleen A. Hanlon, VMD, PhD, CDC, Atlanta, Ga; Gregory R. Istre, MD, Pediatric Infectious Diseases Associates, Dallas, Tex; Suzanne R. Jenkins, VMD, MPH, DACVPM, Virginia Department of Health, Richmond; John W. Krebs, MS, CDC, Atlanta, Ga; Ethleen Lloyd, MS, CDC, Atlanta, Ga; Robert B. Miller, DVM, MPH, DACVPM, USDA, Veterinary Biologics, Ames, Iowa; Susan U. Neill, PhD, MBA, Texas Department of Health, Austin; Kenrad E. Nelson, MD, Johns Hopkins University, Baltimore, Md; Victor F. Nettles, DVM, Southeastern Cooperative Wildlife Disease Study, the University of Georgia, Athens; Donald L. Noah, DVM, MPH, DACVPM, US Air Force, Frederick, Md; James G. Olson, PhD, CDC, Atlanta, Ga; James W. Powell, MS, Wisconsin State Laboratory of Hygiene, Madison; Charles E. Rupprecht, VMD, MS, PhD, CDC, Atlanta, Ga; Leon Russell, DVM, MPH, PhD, DACVPM, College of Veterinary Medicine, Texas A&M University, College Station; David P. Schnurr, PhD, State of California, Department of Health Services, Berkeley; Dennis Slate, PhD, USDA, Animal and Plant Health Inspection Service, Wildlife Services, Concord, NH; Jean S. Smith, MS, CDC, Atlanta, Ga; Charles V. Trimarchi, MS, New York State Department of Health, Albany; Cynthia Warner, PhD, CDC, Atlanta, Ga; William G. Winkler, DVM (retired), Stone Mountain, Ga; James H. Wright, DVM, MPVM, DACVPM, Texas Department of Health, Austin.

[a]Garner N. A two year Trap-Vaccinate-Release program targeting raccoons on the Delmarva Peninsula. Maryland Department of Health: Unpublished report, 1989.

[b]Markey B, Dieter JA, Nuss JL, et al. An experimental trap-vaccinate-release program for urban raccoon rabies control (abstr), in *Proceedings*. 38th Annu Conf Wildl Dis Assoc 1989;49.

[c]Stehman SM, Bigler LL, Lein DH. A three year summary of a trap-vaccinate-release rabies vaccination program in central New York with comments regarding pubic attitudes about wildlife rabies vaccination (abstr), in *Proceedings*. 5th Int Meet Rabies Am 1994;38.

References

1. Hanlon CA, Rupprecht CE. The reemergence of rabies. In: Scheld WM, Armstrong D, Hughes JB, eds. *Emerging infections 1.* Washington, DC: American Society for Microbiology, 1998;59–80.

2. Krebs JW, Smith JS, Rupprecht CE, et al. Rabies surveillance in the United States during 1997. *J Am Vet Med Assoc* 1998;¨ 213:1713–1728.

3. Smith JS, Orciari LA, Yager PA. Molecular epidemiology of rabies in the United States. *Semin Virol* 1995;6:387–400.
4. Clark KA, Neill SU, Smith JS, et al. Epizootic canine rabies transmitted by coyotes in south Texas. *J Am Vet Med Assoc* 1994;¨ 204:536–540.
5. Centers for Disease Control and Prevention. Translocation of coyote rabies—Florida, 1994. *MMWR Morb Mortal Wkly Rep* 1995;44:580–587.
6. Steck F, Wandeler A. The epidemiology of fox rabies in Europe. *Epidemiol Rev* 1980;2:71–96.
7. Bogel K, Moegle H, Knorpp F, et al. Characteristics of the spread of a wildlife rabies epidemic in Europe. *Bull World Health Organ* 1976;54:433–447.
8. Bacon PJ, ed. *Population dynamics of rabies in wildlife*. New York: Academic Press Inc, 1985.
9. Clark WR, Fritzell EK. A review of population dynamics of furbearers. In: McCullough DR, Barrett RH, eds. *Wildlife 2001: populations*. London, England: Elsevier, 1992;899–910.
10. Preston EM. Computer simulated dynamics of a rabies-controlled fox population. *J Wildl Manage* 1973;37:501–512.
11. Rosatte RC, Kelly-Ward P, MacInnes CD. A strategy for controlling rabies in urban skunks and raccoons. In: Adams LW, Leedy DL, eds. *Integrating man and nature in the metropolitan environment*. Columbia, Md: the National Institute of Urban Wildlife, 1987;161–167.
12. Carey AB, Giles RH Jr, McLean RG. The landscape epidemiology of rabies in Virginia. *Am J Trop Med Hyg* 1978;¨ 27:573–580.
13. Wandeler AI, Capt S, Gerber H, et al. Rabies epidemiology, natural barriers and fox vaccination. *Parassitologia* 1988;30:53–57.
14. Carey AB, McLean RG. The ecology of rabies: evidence of co-adaptation. *J Appl Ecol* 1983;20:777–800.
15. Anderson RM, Jackson HC, May RM, et al. Population dynamics of fox rabies in Europe. *Nature* 1981;289:765–771.
16. USDA. Proceedings from a symposium. In: Kreeger TJ, ed. *Contraception in wildlife management*. Washington, DC: US Government Printing Office, 1997;1–272.
17. Siemer WF, Brown TL, Stehman, SM, et al. *Public perceptions of rabies and proposed oral bait vaccination trial*. HDRU Series Pub. Ithaca, NY: Cornell University, 1994;94–97:1–38.
18. Debbie JG. Rabies control of terrestrial wildlife by population reduction. In: Baer GM, ed. *The natural history of rabies*. 2nd ed. Boca Raton, Fla: CRC Press Inc, 1991;477–489.
19. Pybus MJ. Rabies and rabies control in striped skunks (*Mephitis mephitis*) in three prairie regions of western North America. *J Wildl Dis* 1988;24:434–449.
20. Thompson JA, Fleming PJ. Evaluation of the efficacy of 1080 poisoning of red foxes using visitation to non-toxic baits as an index of fox abundance. *Wildl Res* 1994;21:27–39.
21. Nixon RM. Executive Order 11643. *Fed Reg* 1972;37:¨ 2875–2876.
22. USDA. *Animal damage control program: final environmental impact statement*. Vol 2–3. Washington, DC: USDA, 1994;1–314.
23. Rosatte RC, Pybus MJ, Gunson JR. Population reduction as a factor in the control of skunk rabies in Alberta. *J Wildl Dis* 1986;22:459–467.
24. MacDonald DW. *Rabies and wildlife: a biologist's perspective*. New York: Oxford University Press, 1980;1–151.
25. Rosatte RC, Power MJ, MacInnes CD, et al. Trap-vaccinate-release and oral vaccination for rabies control in urban skunks, raccoons and foxes. *J Wildl Dis* 1992;28:562–571.
26. Baer GM, Abelseth MK, Debbie JG. Oral vaccination of foxes against rabies. *Am J Epidemiol* 1971;93:487–490.
27. Steck F, Wandeler A, Bischel P, et al. Oral immunization of foxes against rabies: laboratory and field studies. *Comp Immunol Microbiol Infect Dis* 1982;5:165–171.
28. Wandeler A. Oral immunization of wildlife. In: Baer GM, ed. *The natural history of rabies*. 2nd ed. Boca Raton, Fla: CRC Press Inc, 1991;485–503.
29. Johnston DH, Voigt DR, MacInnes CD, et al. An aerial baiting system for the distribution of attenuated or recombinant rabies vaccines for foxes, raccoons, and skunks. *Rev Infect Dis* 1988;10(suppl):660–664.
30. Hadidian J, Jenkins SR, Johnston DH, et al. Acceptance of simulated oral rabies vaccine baits by urban raccoons. *J Wildl Dis* 1989;25:1–9.
31. Hanlon CL, Hayes DE, Hamir AN, et al. Proposed field evaluation of a rabies recombinant vaccine for raccoons (*Procyon lotor*): site selection, target species characteristics, and placebo baiting trials. *J Wildl Dis* 1989;25:555–567.
32. Perry BD, Garner N, Jenkins SR, et al. A study of techniques for the distribution of oral rabies vaccine to wild raccoon populations. *J Wildl Dis* 1989;25:206–207.
33. Bruggemann EP. Rabies in the mid-Atlantic states—should raccoons be vaccinated? *Bioscience* 1992;42:694–699.
34. McGuill MW, Kreindel SM, DeMaria A, et al. Knowledge and attitudes of residents in two areas of Massachusetts about rabies and an oral vaccination program in wildlife. *J Am Vet Med Assoc* 1997;211:305–309.
35. Meltzer M. Assessing the costs and benefits of an oral rabies vaccine for raccoon rabies: a possible model. *Emerg Infect Dis* 1996;2:343–349.
36. Uhaa IJ, Dato VM, Sorhage FE, et al. Benefits and costs of using an orally absorbed vaccine to control rabies in raccoons. *J Am Vet Med Assoc* 1992;201:1873–1882.
37. Kieny MP, Lathe R, Drillien R, et al. Expression of the rabies virus glycoprotein from a recombinant vaccinia virus. *Nature* 1984;312:163–166.
38. Wiktor TJ, MacFarlan RI, Reagan KJ, et al. Protection from rabies by a vaccinia virus recombinant containing the rabies virus glycoprotein gene. *Proc Natl Acad Sci U S A* 1984;81:7194–7198.
39. Wiktor TJ, MacFarlan RI, Dietzschold B, et al. Immunogenic properties of vaccinia recombinant virus expressing the rabies glycoprotein. *Annales de l'Institut Pasteur Virology* 1985;136:405–411.

40. Rupprecht CE, Wiktor TJ, Johnston DH, et al. Oral immunization and protection of raccoons (*Procyon lotor*) with a vaccinia-rabies glycoprotein recombinant virus vaccine. *Proc Natl Acad Sci U S A* 1986;83:7947–7950.
41. Rupprecht CE, Dietzschold B, Koprowski H, et al. Development of an oral wildlife rabies vaccine: immunization of raccoons by a vaccinia-rabies glycoprotein recombinant virus and preliminary field baiting trials. In: Chanock RM, Lerner RA, Brown F, et al, eds. *Vaccines 87, modern approaches to new vaccines: prevention of AIDS and other viral, bacterial, and parasitic diseases*. New York: Cold Spring Harbor Laboratory, 1987; 389–392.
42. Rupprecht CE, Hamir AN, Johnston DH, et al. Efficacy of a vaccinia-rabies glycoprotein recombinant virus vaccine in raccoons (*Procyon lotor*). *Rev Infect Dis* 1988;10 (suppl):803–809.
43. USDA. Availability of environmental assessment and finding of no significant impact. *Fed Reg* 1995;60:20476–20477.
44. Hanlon CA, Neizgoda M, Hamir AN, et al. First North American field release of a vaccinia-rabies glycoprotein recombinant virus. *J Wildl Dis* 1998;34:228–239.
45. Roscoe DE, Holste WC, Sorhage FE, et al. Efficacy of an oral vaccinia-rabies glycoprotein recombinant vaccine in controlling epidemic raccoon rabies in New Jersey. *J Wildl Dis* 1998;34:752–763.
46. Robbins AH, Borden MD, Windmiller BS, et al. Prevention of the spread of rabies to wildlife by oral vaccination of raccoons in Massachusetts. *J Am Vet Med Assoc* 1998;213:1407–1412.
47. Fearneyhough MG, Wilson PJ, Clark KA, et al. Results of an oral rabies vaccination program for coyotes. *J Am Vet Med Assoc* 1998;212:498–502.
48. Linhart SB, Kappeler A, Windberg LA. A review of baits and bait delivery systems for free-ranging carnivores and ungulates. In: Kreeger TJ, ed. *Contraception in wildlife management*. Washington, DC: US Government Printing Office, 1997;69–132.
49. Linhart SB. Acceptance by wild foxes of certain baits for administering antifertility agents. *NY Fish Game J* 1964;11:69–77.
50. Dunbar BS. Contraception in domestic and wildlife animal populations using zona pellucida immunogens. In: Kreeger TJ, ed. *Contraception in wildlife management*. Washington, DC: US Government Printing Office 1997;1–9.
51. Turner JW, Kirkpatrick J, Irwin KM. Immunocontraception in white-tailed deer. In: Kreeger TJ, ed. *Contraception in wildlife management*. Washington, DC: US Government Printing Office, 1997;147–160.
52. Tyndale-Biscoe CH. Immunosterilization for wild rabbits: the options. In: Kreeger TJ, ed. *Contraception in wildlife management*. Washington, DC: US Government Printing Office, 1997;223–234.
53. Hanlon CA, Rupprecht CE. Considerations for immunocontraception among free-ranging carnivores: the rabies paradigm. In: Kreeger TJ, ed. *Contraception in wildlife management*. Washington, DC: US Government Printing Office, 1997;185–194.
54. Kreeger TJ. Overview of delivery systems for the administration of contraceptives to wildlife. In: Kreeger TJ, ed. *Contraception in wildlife management*. Washington, DC: US Government Printing Office, 1997;29–48.
55. Gill RB. Thunder in the distance: the emerging policy debate over wildlife contraception. In: Kreeger TJ, ed. *Contraception in wildlife management*. Washington, DC: US Government Printing Office, 1997;257–268.
56. Centers for Disease Control and Prevention. Rabies prevention—United States. *MMWR Morb Mortal Wkly Rep* 1999;48(RR-1):1–21.
57. Nielsen L. Definitions, considerations, and guidelines for translocation of wild animals. In: Nielsen L, Brown RD, eds. *Translocation of wild animals.* Milwaukee, Wis: Wisconsin Humane Society Inc and the Caesar Kleberg Wildlife Research Institute, 1988;15–21.
58. Jenkins SR, Winkler WG. Descriptive epidemiology from an epizootic of raccoon rabies in the middle Atlantic states, 1982–1983. *Am J Epidemiol* 1987;126:429–437.
59. Nettles VF, Shaddock JH, Sikes K, et al. Rabies in translocated raccoons. *Am J Public Health* 1979;69:601–602.
60. Smith JS, Summer JW, Roumillat LF, et al. Antigenic characteristics of isolates associated with a new epizootic of raccoon rabies in the United States. *J Infect Dis* 1984;149: 769–774.
61. Clark J, Widner M. *Fox pens in the Southeast*. In: Min 1st Southeast Furbearer Workshop 1987.
62. Baker OE. Covert investigations related to South Carolina fox pens. In: Minutes of the Fourth Southeastern Furbearer Workshop;1990; Robbinsville, NC.
63. Baker OE. Synopsis of actions taken on the Southeastern Fur Resources Committee's fox pen resolution. In: Minutes of the Fifth Southeastern Furbearer Workshop;1991;Hampton County, SC.
64. The Lacey Act. 18 U.S.C. 42; 16 U.S.C. 3371-3378 (1988).